ENERGY ABSORBER FOR VEHICLE OCCUPANT SAFETY AND SURVIVABILITY (U)

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ABSTRACT (U)

(U) A DESIGN WAS DEVELOPED FOR A NEW TYPE OF IMPACT ENERGY ABSORBER. THIS DEVICE WOULD BE EXPECTED TO DEMONSTRATE FAVORABLE APPLICATION TO VEHICLE OCCUPANT SAFETY IN CRASH AND SECONDARY IMPACT EVENTS. SIMULATION DATA INVOLVING IMPACTS BETWEEN AN ANTHROPOMETRIC DUMMY HEAD AND THE ABSORBER IS PRESENTED TO ILLUSTRATE OCCUPANT PROTECTION PERFORMANCE UNDER VARIOUS IMPACT LOADING CONDITIONS.

(U) Introduction

(U) As a result of stiff interior body panels and several other features of the upper interiors of various combat and tactical vehicles, there is an opportunity to improve vehicle safety and survivability, with respect to head impact protection, by means of appropriately designed passive impact energy absorbers. The impact protection of a novel metal fin design for such an energy absorber was investigated using finite element models to simulate the impact between a 50th percentile anthropometric test device head and various configurations of the absorber.

(U) At first, a classical 2^3 full factorial experimental design was used to investigate the feasibility of the device given reasonable values for impact absorber parameters. Subsequently, analyses were performed in order to characterize the effects of fin rotation. An improvement was made to the design and the effects of the change on performance were measured. Finally, results were compared for tactical vehicle front header / windshield simulations with and without installation if a metal fin absorber.

(U) Motivation for the use of vehicle upper interior impact absorbers

(U) The interior surfaces of combat vehicles are, in general, relatively stiff due to armor requirements. In addition, tactical vehicle body panels are becoming progressively less compliant as armor protection level is increased. As a result, these hard surfaces in vehicle interiors can pose a head injury hazard to occupants during collisions and roll-overs. These hard surfaces can also leave occupants vulnerable to the effects of secondary impacts that sometimes occur subsequent to blast events. Modification of the space around turret rings and other vehicle interior assemblies offers additional opportunity for reduction of the severity of head impact.

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(U) Soldiers typically wear helmets during vehicle operations, but, aside from the case of helmets used by paratroopers, helmets have been designed primarily for ballistic protection and have not historically been required to meet any blunt impact protective requirements (ref. 1). Furthermore, the amount of space available in helmets for blunt impact protection is significantly less than the amount of space available overall in vehicle interiors. This increased space for impact attenuation treatments in vehicle interiors offers an opportunity for more effective reduction of blunt impact severity.

(U) For the case of civilian vehicles, impacts between the head and the upper interior components - including pillars, side rails, headers, and roofs - of civilian vehicles are the leading cause of head injury for non-ejected occupants killed in crashes (ref. 2). The US National Highway Transportation Safety Administration (NHTSA) updated Federal Motor Vehicle Safety Standard (FMVSS) No. 201 to address this issue by requiring that civilian vehicles pass tests that involve the 15 mph impact between a 50th percentile Hybrid III anthropometric test device head and various target locations in the vehicle upper interior (ref. 3). Finally, the TACOM Tactical Vehicle Occupant Crash Protection Handbook, based on US Army Safety Center data for light tactical vehicle crash data from 1985-1997, stated that head injuries were the most frequent severe injuries in all mishap categories and suggested that the majority of these injuries resulted from head contact with interior vehicle surfaces (ref. 4).

(U) <u>Simulation methodology</u>

(U) The LS-Dyna explicit finite element solver (ref. 5) was used for modeling and simulation of the large displacement, nonlinear transient impact events. Component level impact evaluations were simulated using 15 mph initial velocity. The impacting body was a validated finite element model of a free motion headform supplied by First Technology Safety Systems. A free motion headform is a 50th percentile Hybrid 3 anthropometric test device head that is modified according to Federal Motor Vehicle Safety Standard (FMVSS) 201U (ref. 3) and instrumented with a tri-axial accelerometer. The simulations were performed in order to develop impact absorbers that will, when mounted on various vehicle upper interior surfaces, enable reduced head impact severity per to the objectives and methodology of FMVSS 201U.

(U) <u>Head Injury Criterion (HIC)</u>

(U) HIC(d), a modified form of the Head Injury Criterion (HIC), was used to estimate the severity of head impact events (ref. 3).

(U)
$$HIC = \max_{t_1,t_2}\left\{\left[\frac{\int_{t_1}^{t_2} a(\tau)d\tau}{(t_2-t_1)}\right]^{2.5}(t_2-t_1)\right\} \quad (1)$$

(U)
$$HIC(d) = 0.75446\ (HIC) + 166.4 \quad (2)$$

(U) HIC(d) is a correlation between free motion headform HIC and HIC for a full 50th percentile anthropometric test device. In the expression for HIC, a(t) is defined as the resultant acceleration as

a function of time, t1 and t2 are any two points in time during the impact separated by not more than 36 milliseconds. Lower HIC is better; FMVSS 201U requires that HIC(d) be less than 1000. The resultant acceleration as a function of time for a typical impact event is shown in Figure 1.

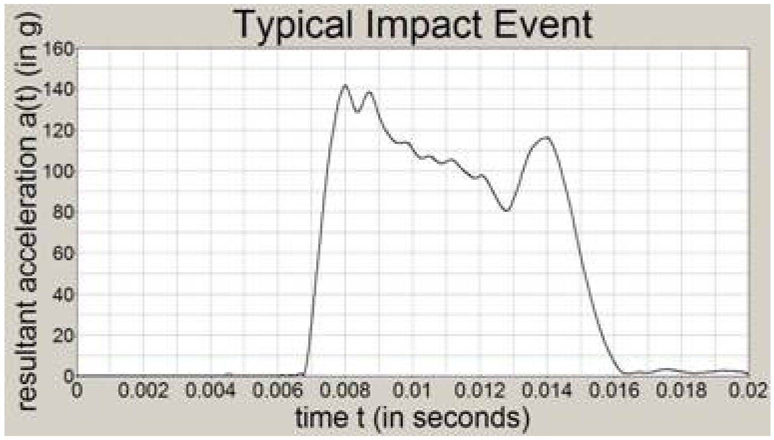

Figure 1. (U) Resultant acceleration during a typical impact event.

(U) Rigid side body panel impact absorption using metal fin absorber

(U) A matrix of metal fins sandwiched between a vehicle interior body panel and a metal cover (Figure 2) transforms kinetic energy of impact to internal strain energy via plastic deformation of cover and fins. It was determined by simulation that absorber performance could be significantly tuned and modified by variation of fin spacing, crush distance, and metal thickness. The fins could

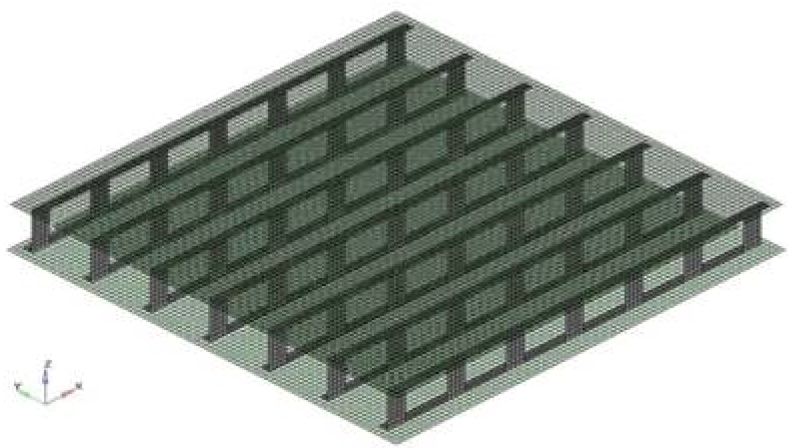

Figure 2. (U) Metal fin energy absorber.

be fastened to the interior panels and the outer metal cover by means of adhesive, spot welds, or rivets. For the purposes of this study, attachments were modeled as spot welds in the center of each of the top and bottom interfaces between the fins and the panels. The mechanical properties of mild steel do not vary significantly over any conceivable range of vehicle interior operating temperatures; device performance would be expected to remain essentially the same for all relevant ambient temperatures.

(U) Initial factorial design investigation for side panel

(U) A 2^3 full factorial screening design with a center point (ref. 6) was performed in order to determine whether the simulated metal fin absorber geometry would perform acceptably given a reasonable amount of crush space. A second objective was to get some sense of how impact performance varied with each of three design variables: fin/cover metal thickness, fin spacing, and crush space. The thickness of the fin / cover system was varied between 0.026 inch and 0.36 inch; the spacing between the fins was set to levels between 1.0 inch and 2.0 inch; and crush space values were adjusted to levels between 1.0 inch and 1.5 inch. The fin / cover material was mild steel; the armor was modeled as a rigid panel.

(U) Reasonable levels of HIC(d) can likely be achieved by the absorber with reasonable levels of crush space (Figure 3), for example, 678 HIC(d) with 1” of crush space. This value of HIC(d) is significantly lower than the requirements of FMVSS 201U which are that HIC(d) be less than 1000.

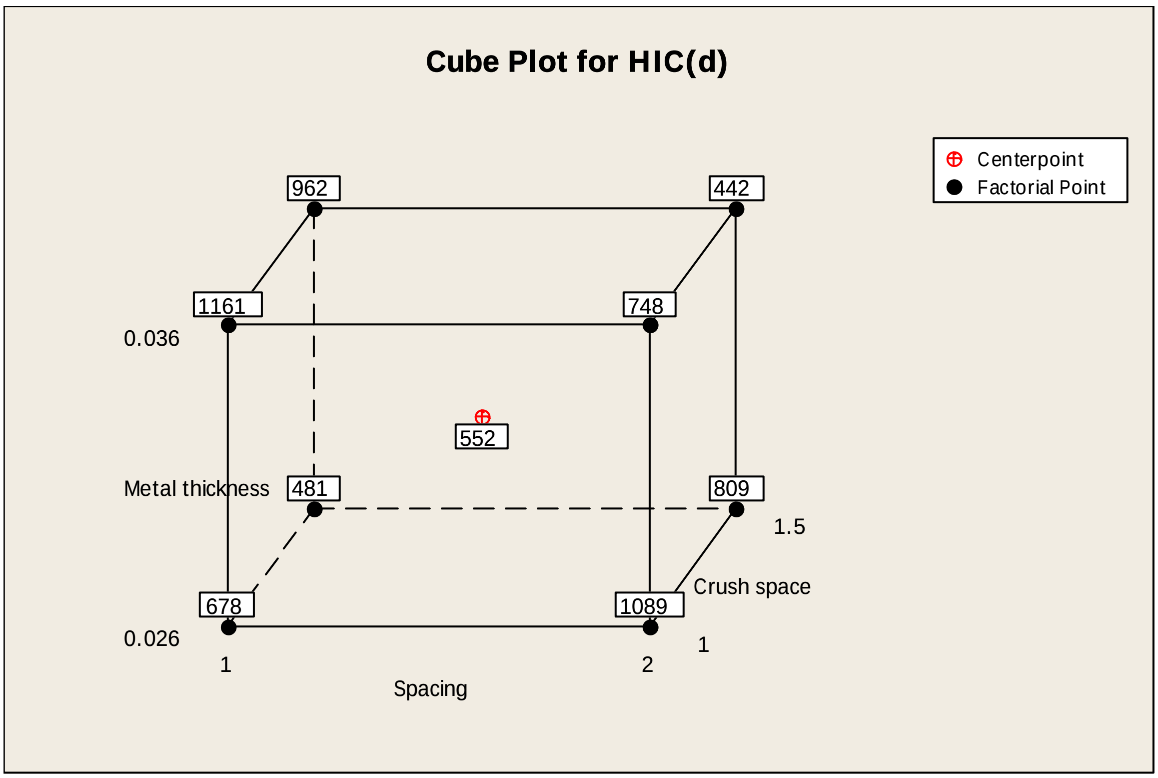

Figure 3. (U) Results of screening design.

(U) An inspection of interaction plots (Figure 4) reveals that, in the mean, there was an interaction between the metal thickness and fin spacing: a low level of spacing with a high level of thickness or a high level of spacing with a low level of thickness seemed to promote lower values for HIC(d). As might be expected, increased crush space allowed for significantly lower levels of HIC(d). A low probability level for the assumption of no curvature effect in the analysis of variance (Table 1) indicates that there is likely some degree of curvature in the HIC(d) response (ref. 7).

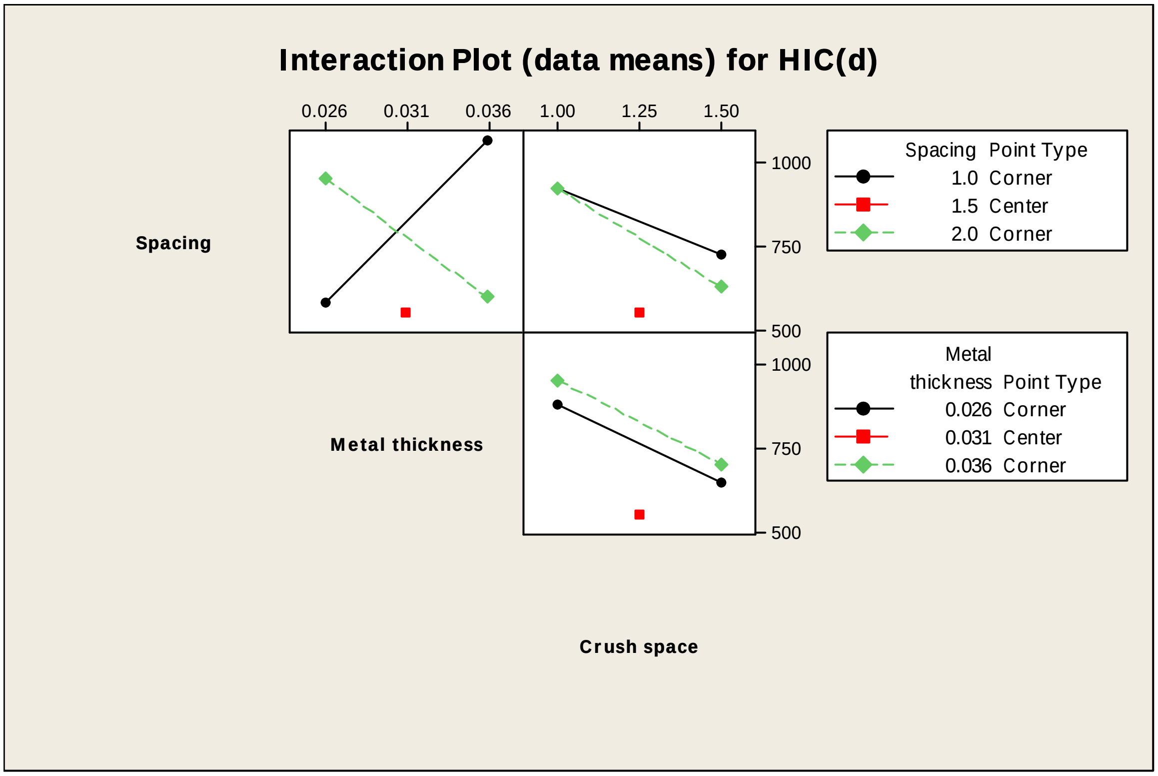

Figure 4. (U) Interaction plots for screening design.

Table 1. (U) Analysis of variance table for screening design.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F	p
Main Effects	3	133437	44479	617.76	0.030
2-Way Interactions	3	354059	118020	1639.16	0.018
Curvature	1	53029	53029	736.52	0.023
Residual Error	1	72	72	72	
Total	8	540597			

(U) <u>The effect of 90° rotation and modified web geometry on impact results</u>

(U) The effect of fin conformation on HIC(d) was evaluated for an absorber with 0.026” fin/cover thickness, 1.2” fin spacing, and 1” of crush space. When the fin orientation was rotated by 90°, HIC(d) increased from 669 (for the case illustrated in Figure 5), to 767 (for the conformation shown in Figure 6).

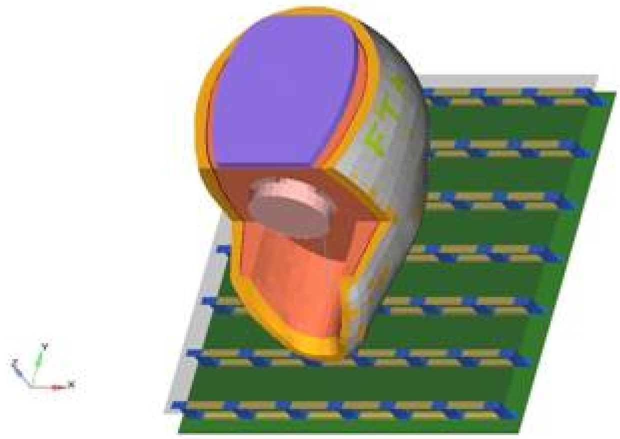

Figure 5. (U) Original fin conformation, HIC(d) = 669.

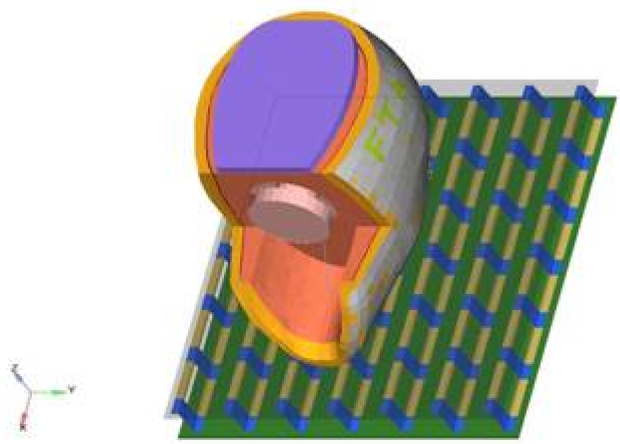

Figure 6. (U) Fins rotated 90°, HIC(d) = 767.

(U) Several modifications were tried in order to try to reduce the variation of the response when the fin conformation was varied by 90°. In the end, it was found that the removal of cross-tie on the top and bottom webs between the fins resulted in a reduction of mean, maximum, and dispersion of HIC(d) results between the conformations (Figures 7 and 8).

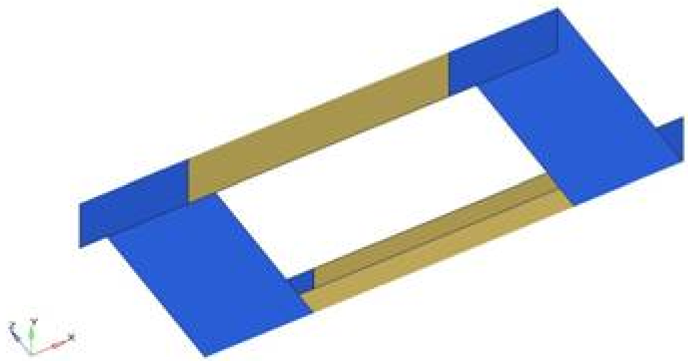

Figure 7. (U) Original connecting web design.

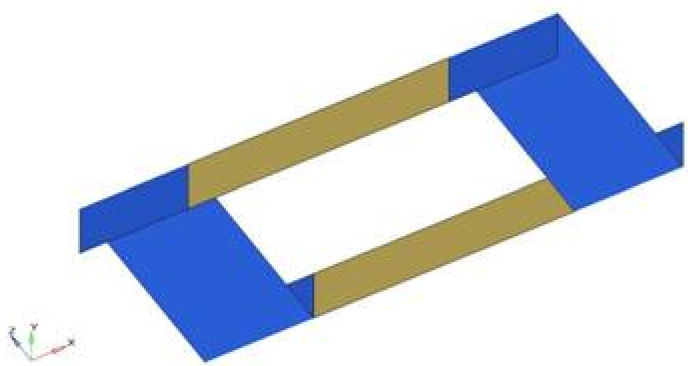

Figure 8. (U) Improved connecting web design – cross-ties were removed from the top and bottom of the web connecting the fins.

(U) HIC(d) results for the new fins with 0.026" fin/cover thickness, 1.2" fin spacing, and 1" of crush space yielded HIC(d) of 658 and 662, respectively, for the 0° and 90° conformations as compared to the HIC(d) of 669 and 767, respectively, that were exhibited by the original web design. A 9 run, 2 level, 3 factor designed experiment with one center point was conducted for the new web geometry at each of the 0° and 90° conformations.

(U) When the 0° conformation results for the two designs were compared (Table 2), it was observed that there was a trend toward reduced mean, minimum, and maximum HIC(d). There also seemed to be an improvement in dispersion as evidenced by the reduction in HIC(d) range from 226 to 126 when a change was made from the original to the new design. The results for the 90° conformation with the new design also showed HIC(d) values significantly lower than 1000.

Table 2. (U) Effect of modified fin geometry.

Geometry	Original	New	New
Conformation	0°	0°	90°
Mean HIC(d)	742	656	654
Min HIC(d)	669	607	630
Max HIC(d)	895	733	684
HIC(d) range	226	126	54

(U) Reduction of severity of front header/windshield impact

(U) Impact simulations were performed on a rigid up-armored tactical vehicle header/windshield system. Although, in practice, one would probably not perform a baseline FMVSS 201U test on an armored panel due to the risk of destroying the components of the free motion headform, modeling was performed in order to estimate HIC(d) without installation of an energy absorber (Figure 9). Baseline HIC(d) was found to be in excess of 7000.

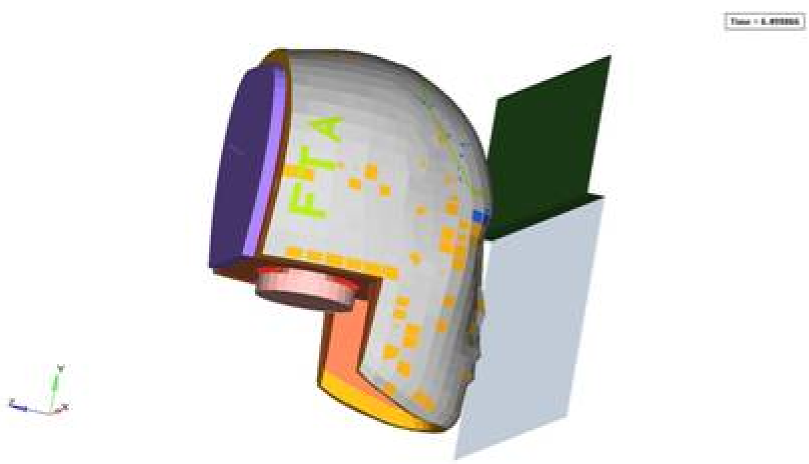

Figure 9. (U) Front header / armored windshield – baseline configuration (no energy absorber), HIC(d) > 7000.

(U) Several metal fin absorber designs for the windshield header were simulated. One of these designs reduced impact severity to about 860 – a reasonable level – by means of metal fin absorber affixed to the front header (Figure 10). The crush space at the bottom of this absorber (intrusion into passenger compartment) was a little bit less than 1"; at the top, a little bit less than 2.25"
There is an opportunity for further optimization of this design.

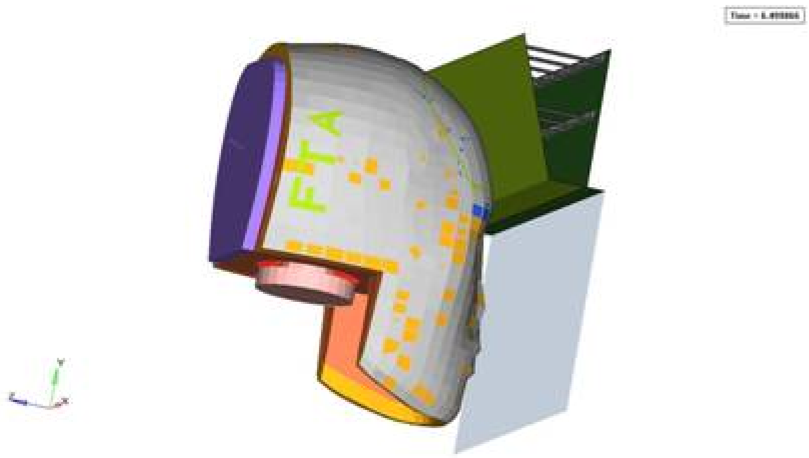

Figure 10. (U) Front header / armored windshield
with energy absorber, HIC(d) = 860.

(U) <u>Conclusions and recommendations</u>

(U) Simulation results for rigid upper interior panels and front headers with metal fin absorbers suggest it is possible to provide significant Soldier head impact protection for rigid body panels using relatively minimal amounts of vehicle interior package space.

(U) Component and vehicle level physical tests of prototypes would provide a suitable means for validation of the finite element models.

(U) Correlated finite element models could be used to develop and optimize designs for various locations in various vehicles.

(U) Application of energy absorbers to vehicle rigid interior surfaces would be expected to save Soldiers' lives during impact events that result from vehicle collisions, from vehicle rollovers, and from secondary impacts due to blasts.

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